COMPARATIVE ANALYSIS OF FULL-TREE AND TREE-LENGTH HARVESTING SYSTEMS IN WESTERN NEWFOUNDLAND

D. Cormier*
P. Meek**
J. Favreau***
J.-F. Gingras****

Forest Engineering Research Institute of Canada
143 Place Frontenac
Pointe Claire, Quebec
H9R 4Z7

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* Denis Cormier, F.E., M.Sc., is a researcher for the Silvicultural Operations group.

** Philippe Meek, F.E., M.Sc., is a researcher for the Wood Harvesting group.

*** Jean Favreau, F.E., M.Sc.E., is a researcher for the Wood Harvesting group.

**** Jean-François Gingras, F.E., is Group Supervisor of the Wood Harvesting group.

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Acknowledgments

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Executive summary

In 1991, Corner Brook Pulp and Paper Ltd. reintroduced full-tree systems to their operations, under the assumption that the technology had matured to the point that modern feller-bunchers, skidders and delimbers would be effective in Newfoundland conditions. Preliminary results from the productivity tracking of these machines seemed to confirm this assumption and Corner Brook Pulp and Paper now intend to harvest around 15 to 20% of their timber using this approach.

Based on recent developments in other provinces where some move away from full-tree logging had started and concerned with the possible negative environmental impacts of this system, the Newfoundland Department of Forestry and Agriculture approached FERIC to conduct a comparative assessment of full-tree logging versus traditional tree-length harvesting in western Newfoundland. FERIC, in cooperation with the provincial government, the company, and Forestry Canada, selected four operational areas dominated by balsam fir near Corner Brook to compare the two harvesting systems in terms of fibre utilization, protection of site integrity, and overall costs including forest renewal and early stand tending expenses. This study should be considered as a case study and thus, the results do not necessarily apply to all Western Newfoundland balsam fir sites.

During the case study, the survey of timber utilization showed only minor differences between the two harvesting systems. The tree-length system left more merchantable volume on the cutover but none at roadside. When the two systems were used on the same site, the tree-length system left slightly less merchantable volume on site overall, but the full-tree system left lower stumps. Therefore, the net volume loss was in favor of full-tree.

In general, the results of this study show no evidence that full-tree logging will affect the regeneration stocking more than tree-length. The stocking after harvest was more abundant for the full-tree system in the only block where both systems were assessed side-by-side. However, the tree-length system with manual felling may offer more potential for protecting advance growth when careful logging techniques are adopted.

Further surveys of the case study blocks are needed to verify if the regeneration after both harvesting systems follows the same evolution pattern. However, even if the type of sites and the systems were not exactly the same, the results of a 13-year-old full-tree and tree-length cut in the Burlington block seem to confirm that the evolution pattern of the natural regeneration after both systems is similar.

In the case study, moderate and severe disturbances were associated with skid trails. Except for more severe ground disturbance bulldozed skid trails in the tree-length sites, both harvesting systems showed comparable site disturbance results.

On the basis of area taken out of forest production without a rehabilitation treatment, there would be around twice the loss of area by the full-tree roadside slash pites than by the landings of the tree-length logging system.

Introduction

Over the years, wood harvesting in Newfoundland has not always followed the patterns observed in other parts of the country. Newfoundland loggers have traditionally been up against some of the most adverse stand and terrain conditions to be found in the Canadian boreal forest. Some logging systems have been successful and stayed around, while others have provided disappointing results and disappeared.

While shortwood and tree-length harvesting have been dominant in Newfoundland in the last decades, full-tree logging had been used in the mid-seventies by Corner Brook Pulp and Paper when several different types and brands of fellers, delimbers, processors and forwarders were tried. None of these efforts led to major successes and were abandoned, mainly because the technology had not fully matured and the machines had numerous problems, especially in the harsh Newfoundland conditions. Full-tree logging was abandoned and up until 1991, all the wood in western Newfoundland was harvested with shortwood or manual tree-length methods. The former accounted for about 75% of the total, while the latter represented roughly 25% of the total harvest.

In 1991, Corner Brook Pulp and Paper Ltd. reintroduced full-tree systems to their operations, under the assumption that the technology had developed to the point that modern feller-bunchers, skidders and delimbers would be effective in Newfoundland conditions. Preliminary results from the productivity tracking of these machines seemed to confirm this assumption and Corner Brook Pulp and Paper now intend to harvest around 15 to 20% of their timber using this approach.

Based on recent developments in other provinces where some move away from full-tree logging had started and concerned with the possible negative environmental impacts of this system, the Newfoundland Department of Forestry and Agriculture approached FERIC to conduct a comparative assessment of full-tree logging versus traditional tree-length harvesting in western Newfoundland. The broad objective of the study was to compare the two systems in terms of protection of site integrity, fibre utilization and overall costs including forest renewal and early stand tending expenses.

FERIC accepted this contract in 1992 and, in cooperation with the provincial government, the company, and Forestry Canada, selected a case study approach in the Corner Brook area to conduct a comparative analysis.

Context

Since the second world war, harvesting systems in eastern Canada have undergone major changes, with each of the three major methods, shortwood, tree-length and full-tree, having its period of glory, as can be seen in Figure 1.

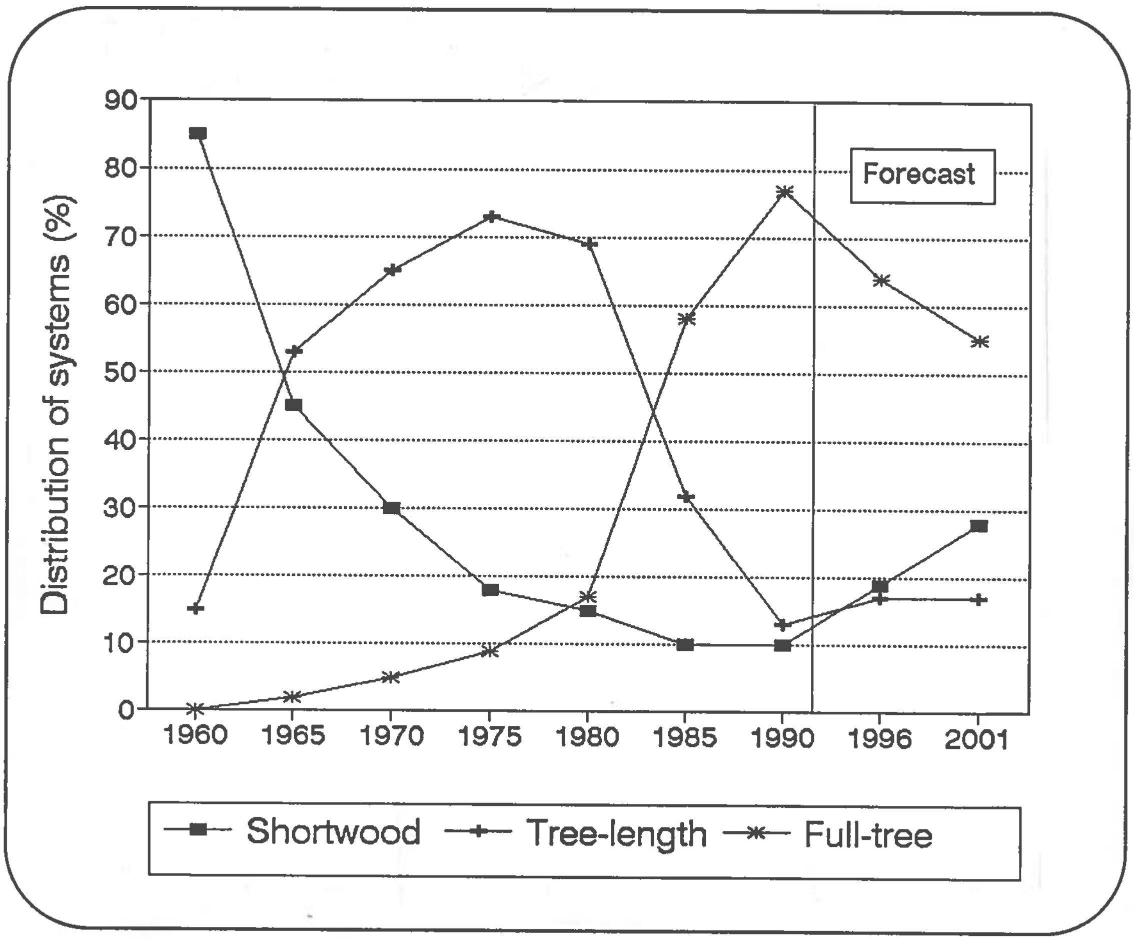

Figure 1. Harvesting system trends, 1960-2001 (adapted from Gingras 1992a; Gingras and Ryans 1992).

Prior to 1960, most of the timber in eastern Canada was harvested with the shortwood method because of the limited mechanization available. With the introduction of lightweight power saws, articulated skidders and hydraulic loaders, it became possible to bring delimbed stems to roadside very productively and the tree-length (or cut and skid) method rapidly became the dominant harvesting approach in the 70's (McNally 1978). In the late 70's, the introduction of roadside stroke delimbers and purpose-built feller-bunchers opened the door to full-tree harvesting. This system was adopted very rapidly in most provinces, especially in Ontario and Quebec. Full-tree methods dominated the 1980's and peaked around 1990. The popularity of this system was dominated the 1980's and peaked around 1990. The popularity of this system was attributed to the high productivity achieved by the single-function machines and their ability to handle a wide range of terrain and stand conditions. These enabled the industry to moderate wood cost increases during those years.

Despite this cost advantage, there have been growing pressures to reduce the volumes harvested with full-tree methods in eastern Canada, primarily because of public demands to reduce the visual impact of roadside slash piles, and for a number of other reasons such as regional legislation, effective marketing from shortwood equipment dealers, ground disturbance levels on certain sites, concerns about protection of advance regeneration, and a shift toward more complex product sorting in the bush. The cost of disposing of roadside debris has also been raised, although this has not been clearly shown to exceed the cost increases associated to switching from full-tree harvesting to other harvesting methods (Desrochers and Ryans 1991). Despite the growing interest in cut-to-length and mechanized tree-length methods, full-tree systems are still expected to harvest nearly 60% of the timber into the year 2001 (Gingras and Ryans 1992).

In Newfoundland, the use of full-tree harvesting offers both advantages and disadvantages which are related to the nature of the terrain and stands present in the province. A mechanized full-tree system using a purpose-built feller-buncher, bunch-slinging cable skidders and roadside stroke delimbers offers cost advantages over manual tree-length and shortwood systems in unfavorable conditions as was shown by Gingras (1992b). The technology level of these machines allows most operators to troubleshoot, repair, maintain and operate them fairly easily. This is often not the case with imported single-grip harvesters. Finally, since a multiple-stem system is less sensitive to tree size than single-stem systems, it can work in stands of very low volume and small tree size (less than 0.1 m^3/tree).

Full-tree harvesting also has some disadvantages. On certain sites, ground disturbance levels may be high because there are no branches and tops to offer any protection. Fibre recovery efficiency may be somewhat lower than with cut-to-length equipment because of fibre losses associated to large-kerf sawheads, high stumps in rocky areas, loss of small stems and breakage during skidding. Also, most companies across Canada using full-tree harvesting must treat the roadside delimbing debris. The reasons include the potential loss of productive area, aesthetics, provincial legislation and fire-hazard reduction. Treatment methods range from burning the debris in-situ, piling usually followed by burning, pushing corridors through the debris, to harvesting the debris for biomass. Further details are given in Desrochers and Ryans (1991), Desrochers et al. (1992) and Luke et al. (1993). FERIC is also preparing a report on the various treatment methods which will be available in 1994. Also, potential nutrient depletion from nutrient exports during full-tree logging will depend on specific site fertility and other ecological factors.

Case study

The comparative case study trial of full-tree and tree-length harvesting systems was done in western Newfoundland on the limits of Corner Brook Pulp and Paper Ltd. Four operational areas dominated by balsam fir were selected near Corner Brook.

To conduct the trial, FERIC cooperated with Corner Brook Pulp and Paper, the Newfoundland Department of Forestry and Agriculture and Forestry Canada (Newfoundland region). Corner Brook Pulp and Paper was responsible for the regeneration surveys and gathering data on productivity and operating costs of both harvesting systems. The Department of Forestry and Agriculture conducted the fibre utilization surveys, assisted with the regeneration surveys and provided logistical support. Forestry Canada provided expertise to assess the severity of soil disturbance and in establishing a sampling procedure to compare the site disturbance created by both harvesting systems. FERIC was responsible for the soil disturbance surveys and the economic analysis of the two harvesting systems including the forest renewal costs. In addition, all the information was consolidated by FERIC.

The full-tree system involved in the case study included mechanical felling with a feller-buncher, skidding with cable or grapple skidders, delimbing at roadside with a stroke delimber and bucking to 2.5-m lengths with a slasher. The tree-length system consisted of manual felling and delimbing, skidding with cable skidder and slashing at roadside with a slasher. A bulldozer was used with the tree-length system to prepare the landings and some skid trails.

The location of the four operational areas is given in Figure 2. The Cooks Pond, Lady Slipper and Camp 10 operational areas were located in the Corner Brook subregion of the western Newfoundland ecoregion (Meades and Moores 1989). The study blocks at Cooks Pond had a rugged topography dominated by Dryopteris-Rhytidiadelphus-Balsam fir forest type. The study block at Lady Slipper was on a homogeneous mid-slope and mainly supported a Dryopteris-Balsam fir forest type. The forest types of Camp 10 were typical of the hilly topography with shallow soil over shale of the western Newfoundland ecoregion. The fourth operational area, located near Hinds Lake, was more typical of the central Newfoundland ecoregion. It was dominated by Hylocomium-Balsam fir forest type.

The harvesting systems used in each block are described in Table 1. Major efforts were concentrated in the Cooks Pond operational area because both systems were used there. All the operations surveyed were cut during the summer.

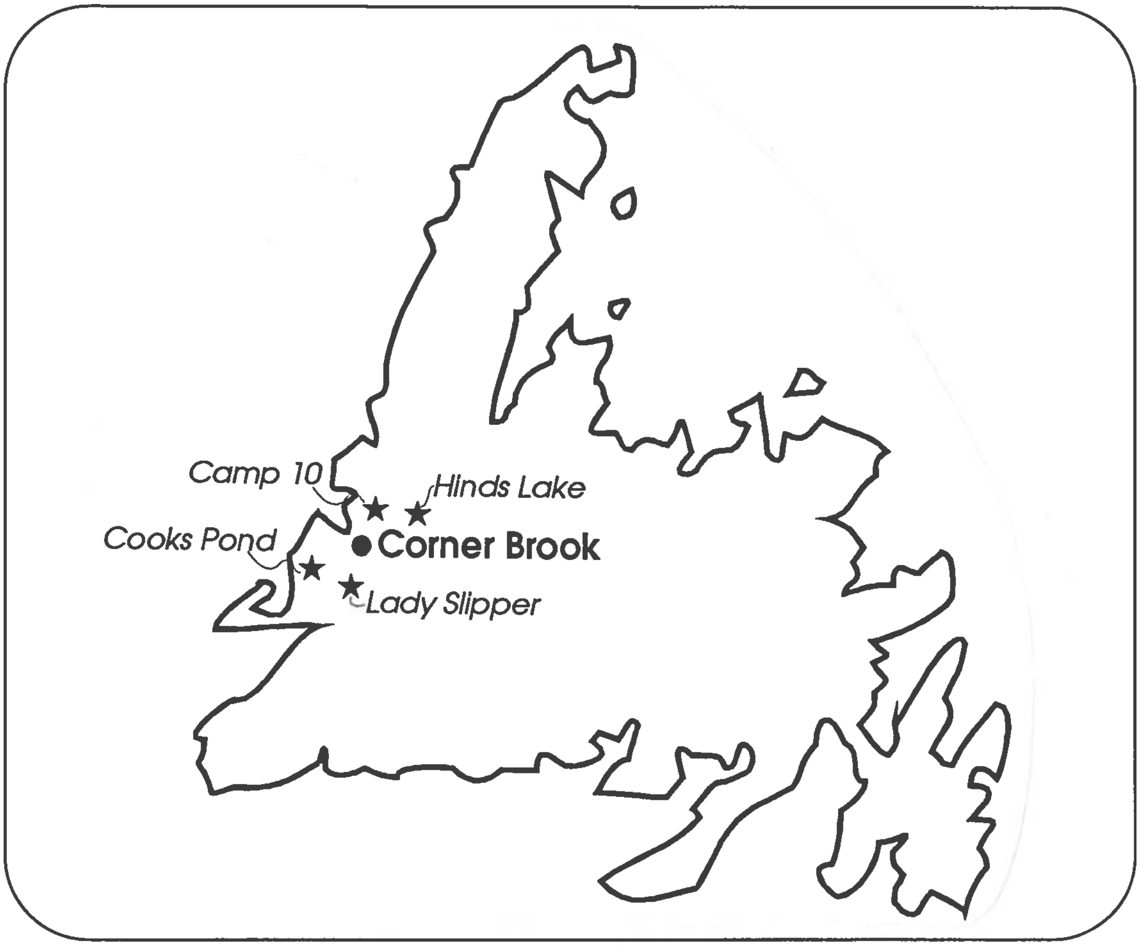

Figure 2. Location of the four operational areas.

Table 1. System used and year of harvest for each harvesting block

Operational area	Harvesting block	Harvesting system	Year of harvest
Cooks Pond			
	Cooks Pond	Tree-length	1990, 1991
	Island Pond	Tree-length	1991
		Full-tree	1992
	Rideouts Pond	Both	1992
	Trussle Block	Both	1992
Lady Slipper		Full-tree	1991
Hinds Lake		Full-tree	1992
Camp 10		Tree-length	1992

Assessment procedures

The case study assessment criteria were timber utilization, protection of natural regeneration, soil disturbances on the cutover and at roadside, and potential area taken out of production. Except for the evaluation of landings and roadside slash, all assessments were done on the actual cutover, not including the road network. Because of operational constraints or lack of comparability, all assessment variables were not measured in every block.

i) Timber utilization

Timber utilization surveys were used to measure the merchantable volume of wood left on the cutovers after full-tree and tree-length harvesting operations. The surveys were done according to the procedure used by the Forest Products and Development Division of the Department of Forestry and Agriculture of Newfoundland (Anonymous 1992). Islands and fringes of standing timber greater than 0.01 ha were not surveyed and were not considered part of the cutover area. Supplementary survey guidelines for the measurement of roadside slash from full-tree operations were also used (Young 1992).

To enable the assessment of cull content (whereby surveys have to be done soon after the cut), only the blocks harvested in 1992 were assessed.

ii) Natural regeneration

Surveys of advance regeneration stocking were based on the regeneration assessment procedure used by Corner Brook Pulp and Paper Ltd. Circular plots of 5-m^2 were evenly distributed over the whole area. In every plot, the regeneration density was tallied by height classes within a 1-m^2 circular plot. Larger 10-m^2 plots surrounding the smaller ones were also used as a measure of site occupancy, which is the standard practice of Corner Brook Pulp and Paper Ltd.

Because of timing and operational constraints, the density and stocking both before and after harvesting were assessed only for the full-tree systems at the Hinds Lake operational area and at the Trussle Block and the Rideouts Pond blocks in the Cooks Pond operational area. Stocking of advance regeneration left after harvesting was measured in all other blocks except for tree-length operations of Rideouts Pond and Trussle Block.

iii) Soil disturbances on the cutover

The soil disturbances created by full-tree and tree-length operations were assessed on two types of site conditions. The easiest terrain conditions for both systems were found in the Island Pond block of the Cooks Pond operational area. Mainly because of their greater slope, the full-tree block at Lady Slipper and the tree-length block at Camp 10 were selected as representative of the more difficult terrain conditions.

A general description of the site after harvest was done using a visual estimation of the ground coverage by type of disturbance in 5-m^2 plots uniformly distributed on the cutover. Ten disturbance types established from the work of Case and Donnelly (1979) were used. A complete definition and illustrations of the disturbance types can be found in Appendix 1. Additional information on the presence of natural regeneration was also collected in the same plots.

Skid trails in each logging system were described and compared. Three skid trail profiles along three different trails were established for each site, as shown in Figure 3. In each trail, the profiles were located immediately behind the landing, at one third of the cutover depth and at two thirds of the cutover depth. The measurement positions in each profile are related to three soil levels: the normal soil surface; the rooting zone; and the C pedogenic horizon. The lower level of the rooting zone was defined to be the point above which 90% of the roots are located. Soil under this level may be considered a less appropriate growing medium for seedlings. It is generally acknowledged that the C horizon presents a poor growing medium.

Three indicators were used to portray the disturbance severity in the skid trails. The first indicator was the volume of soil compacted or removed along the trail (the average profile area under the soil surface level multiplied by the length of the trail). The other two indicators consisted of the surface area of exposed soil at the rooting zone and at the B/C interface. The area was the average width at the respective levels multiplied by the length of the trail. The indicators were put on a per-ha basis by using the average distance between trails.

iv) Landings and roadside slash

The area covered by landings and roadside slash was measured to evaluate the potential area that would be taken out of forest production. This assessment was made in the same four sites as for the site disturbance survey. Data collected for the timber utilization survey in the Trussle Block and Rideouts Pond blocks were also used to evaluate the ground coverage of roadside slash during full-tree logging.

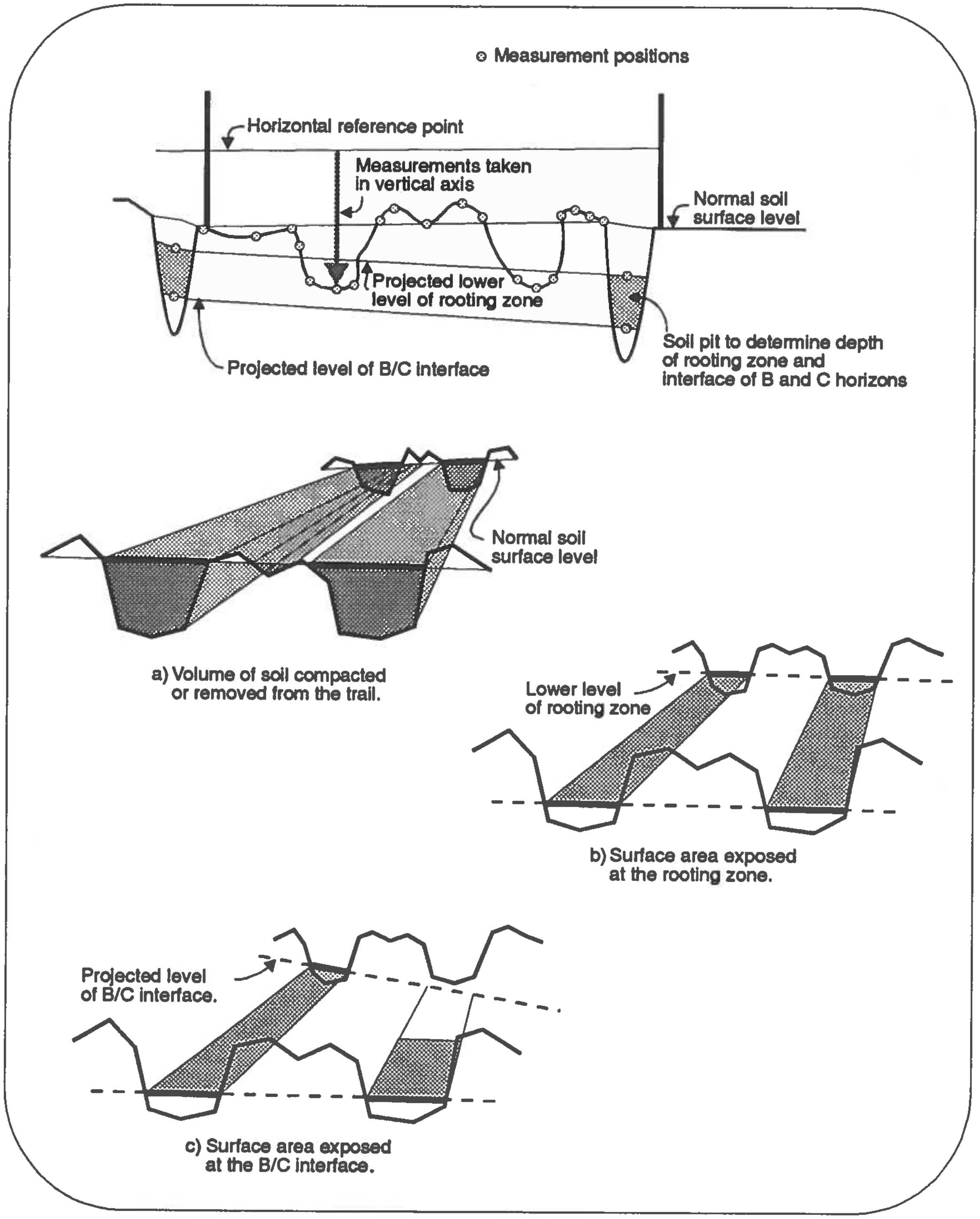

Figure 3 . Measurement positions from the horizontal and vertical axis used to describe the profile of the skid trail. Volume and surface area calculations were made in the shaded sections.

Results

i) Timber utilization

The volume of merchantable fibre left on the ground or in roadside slash piles after harvesting for full-tree and tree-length systems is shown in Table 2. This table also shows the gain of volume for low stumps according to provincial standards. The results indicate a slight difference between sites but no major difference between harvesting systems. The sites where both systems were monitored for timber utilization had a difference of only 1.2 m^3/ha in favor of full-tree when considering the total solid wood fibre (cutover, roadside slash and low stumps). The difference was a result mainly of a larger gain from low stumps during the full-tree operations.

Table 2. Evaluation of the timber utilization of full-tree (FT) and tree-length (TL) harvesting.

Location	Logging method	Solid wood fiber (m^3/ha)			Net loss (m^3/ha)
		Loss		Gain	
		cutover	roadside slash[1]	Low stumps	
Cooks Pond					
Island Pond	FT	7.0	N.A.	2.2	-
Rideouts Pond	FT	4.4	2.4	4.1	2.7
	TL	5.9	0.0	2.0	3.9
Trussle Block	FT	6.5	2.3	2.6	6.2
	TL	8.6	0.0	1.2	7.4
Camp 10	TL	4.1	0.0	N.A.	-
Hinds Lake	FT	3.9	N.A.	0.5	-

[1]Merchantable fibre volume estimated from the gross merchantable volume using the same percentage of cull wood as for the cutover.

ii) Natural regeneration

The stocking of natural regeneration after harvest was assessed in five full-tree and three tree-length blocks (Table 3). Comparison between the two systems on the protection of advance regeneration is difficult since only three full-tree logging operations were surveyed before harvesting. However, the stocking remaining after logging was around 50% for all the sites surveyed. For the three presampled full-tree blocks, the reduction in stocking ranged from 25 to 50%, which can partly be explained by the differences in site conditions.

The Island Pond block is the only site where figures are available for side-by-side comparison. There, the stocking of advance regeneration after logging is greater with the full-tree system. However, differences in the timing of the cut and lack of preharvest information make any conclusions difficult.

In their regular regeneration survey procedures, Corner Brook Pulp and Paper measures the stocking in 5- and 10-m^2 plots. While the 5-m^2 plot corresponds to the provincial stocking standard, the larger plot is used to give a better evaluation of the site occupancy of the regeneration. For a given stocking (5-m^2 plot), a larger difference between the two sized plots corresponds to a better site occupancy. The use of both stockings may help guide regeneration decisions. For example, a regeneration effort would probably be directed toward a site with a stocking (5-m^2 plot) of 50% covering 60 % of the area (10-m^2 plot) rather than toward a site with the same stocking covering 85% of the area. In this case study, the regeneration left after harvesting is quite clumped. With differences ranging from 4 to 13%, the distribution of the regeneration closely follows the stocking pattern (Table 3). In the best case, 36% of the area was unoccupied after harvesting.

Table 3. Stocking and distribution of natural regeneration

Location	Logging method	Pre-harvest stocking (%)		Post-harvest stocking (%)		Stocking loss (%)	
		5-m^2 plot	10-m^2 plot	5-m^2 plot	10-m^2 plot	5-m^2 plot	10-m^2 plot
Cooks Pond							
Cooks Pond	TL	-	-	49	53	-	-
Island Pond	FT	-	-	48	55	-	-
	TL	-	-	40	47	-	-
Rideouts Pond	FT	76	83	51	64	25	19
Trussle Block	FT	86	95	53	57	33	38
Lady Slipper	FT	-	-	55*	-	-	-
Camp 10	TL	-	-	53*	-	-	-
Hinds Lake	FT	99	100	49	55	50	45

* from FERIC survey

The reduction of seedling density was monitored for three full-tree operations (Table 4). The number of seedlings remaining after harvest represent a loss of 80 to 90% of the initial densities. Considering the stocking, the density may still be considered high. Similarly, a post-treatment assessment done by FERIC on the Lady Slipper full-tree block and on the Camp 10 tree-length block showed a density of 8470 and 6700 seedlings/ha respectively.

Regeneration surveys of older full-tree and tree-length cuts were also conducted during the summer of 1992 by the Department of Forestry and Agriculture to see if the regeneration established after both types of harvesting systems followed the same pattern. However, the type of sites and the systems were not exactly the same as in the case study blocks. The surveys were done in the Burlington block near Springdale (Gull Pond area) in the Northcentral subregion of the central Newfoundland ecoregion (Meades and Moores 1989). Thirteen years after logging, stocking based on 5-m^2 plots was 90% for the full-tree area and 89% for the tree-length area.

Table 4. Density reduction of natural regeneration on three full-tree operations.

Height class	Density (stems/ha)					
	Rideouts Pond		Trussle Block		Hinds Lake	
	Pre	Post	Pre	Post	Pre	Post
0-5 cm	8100	900	27100	4000	38200	2900
6-15 cm	16500	3900	23600	4 700	24500	1200
16-30 cm	11400	3000	16300	3100	4 700	900
>30 cm	3200	0	8100	1800	3000	2000
Total	39200	7800	75100	13600	70400	7000
Loss (%)	80		82		90	

iii) Soil disturbances

Two types of site conditions were selected to evaluate soil disturbances created by full-tree and tree-length harvesting. Table 5 provides a description of each site based on ground strength, roughness and slope according to the CPPA terrain classification (Mellgren 1980). The ground bearing capacity ranged from good to moderate. The four harvesting blocks presented a similar ground roughness. The difference in slope between the blocks created two levels of operational difficulty. The flat site at Island Pond presented easier site conditions whereas the Lady Slipper and Camp 10 blocks were considered more difficult because of their greater slope.

Table 6 provides a description of the coverage by type of disturbance after harvesting. Because of the amount of slash left on the cutover after tree-length logging, evaluation of the soil disturbance was not possible on approximately 30% of each site compared to less than 10% for full-tree sites. However, it was assumed that slash coverage acted as a mat and would have allowed only a light disturbance of the soil underneath. Higher amounts of mineral soil deposits and shallow mineral soil exposure on the full-tree sites reflect the absence of designated skid trails and the tendency of the skidder operator to travel over more area (greater percentage of area showing machine passage). The intensive use of bulldozed skid trails on the tree-length site at Camp 10 created a greater amount of deep mineral soil exposure.

Table 5. Site description using the CPPA terrain classification (site coverage (%) per class of terrain condition).

CPPA Terrain Classification	Island Pond		Lady Slipper	Camp 10
	FT	TL	FT	TL
Ground strength				
good	79	88	38	82
moderate	19	12	57	12
poor	2	0	5	6
Ground roughness				
very even	100	94	100	99
slightly uneven	0	4	0	1
uneven	0	2	0	0
Slope				
0-10%	98	97	0	0
11-20%	1	2	10	10
21-33%	1	1	88	82
34-50%	0	0	2	8

Table 6. Soil disturbance coverage (%) after harvesting.

Disturbance class		Easy terrain		Hilly terrain	
		Island Pond		Lady Slipper	Camp 10
	Type of soil disturbance	FT	TL	FT	TL
Light	-undisturbed or vegetation slightly scuffed	37.6	28.9	34.2	28.3
	-humus disturbed	33.8	25.3	37.2	22.5
	-no disturbance possible (stump, rocks,...)	0.8	0.8	0.6	0.5
	-no evaluation possible (slash)	5.8	34.8	10.2	29.3
Moderate	-mineral soil deposit	3.1	1.0	3.9	2.6
	-shallow mineral soil exposure	16.1	5.9	7.2	2.8
	-mix of mineral soil and organic matter	0.6	0.2	1.6	0.0
Severe	-deep mineral soil exposure	1.9	2.1	4.8	12.3
	-mineral or organic muck	0.3	1.0	0.2	1.6
	-erosion features	0.0	0.0	0.1	0.1
Total		100	100	100	100

To facilitate the interpretation of the results, the soil disturbances were regrouped into three disturbance classes (Tables 6 and 7). Surfaces without mineral or organic soil exposure were considered to be only lightly disturbed. Shallow surface layer disturbances with mineral soil exposure were classified as moderate. The severe class included any mineral or organic soil exposure deeper than the rooting zone, muck, or soil showing erosion features. A statistical analysis was done to compare the disturbance severity of full-tree and tree-length logging in easy and difficult site conditions (Table 7). The tree-length method showed the lightest disturbances in easy ground conditions but also more severe in difficult conditions. The significantly greater amount of severe disturbances at Camp 10 was mostly caused by its intensive network of bulldozed skid trails. The absence of designated skid trails during full-tree logging created more moderate disturbances. Because of the slope in the Lady Slipper block, the skidder passes were more concentrated, causing fewer moderate disturbances but slightly more severe disturbances than the Island Pond full-tree block.

Table 7. Comparison of ground coverage (%) per class of disturbance classes for full-tree and tree-length harvesting*.

Disturbance class	Easy terrain		Hilly terrain	
	Island Pond		Lady Slipper	Camp 10
	FT	TL	FT	TL
Light disturbance	78[a]	90	82[a]	81[a]
Moderate disturbance	20	7[b]	13	5[b]
Severe disturbance	2[c]	3[c]	5[c]	14

*Common letter indicate means which are not significantly different at $\alpha<0.05$

The use of bulldozers to clear skid trails after preparing the landing is a common practice for tree-length operations in Newfoundland. Bulldozed skid trails were defined as trails where the top layers and the stumps had been scraped away. Even if they were severely compacted, skid trails with stumps and organic material between the two wheel ruts were not considered as having been bulldozed.

Skid trails for each cutover were selected randomly from aerial photographs or field reconnaissance. During the field reconnaissance, it was noted that none of the trails in the selected full-tree sites were bulldozed. Conversely, all major trail segments leading to a landing for the selected tree-length sites were bulldozed. Bulldozed skid trails covered 3.9% of the area at Island Pond and 6.5% at Camp 10.

The trail profiles are given in Table 8. The bulldozed skid trails used for tree-length logging tended to be wide but fairly spaced out. The total volume of soil removed from the trails was similar for all the sites except for Camp 10 where it was about 25% higher. The surface of exposed soil under the rooting zone and the B horizon was affected both by the site and by the logging system. The tree-length system exposed a larger area of soil under the B horizon. The quantity of exposed soil under the rooting zone was greater on the two difficult sites at Lady Slipper and Camp 10. The influence of the site conditions were more important for the tree-length system where the surface of exposed soil under the rooting zone and under the B horizon was doubled on the more difficult site.

Table 8. Description of the skid trails.

	Easy terrain		Hilly terrain	
	Island Pond		Lady Slipper	Camp 10
	FT	TL	FT	TL
Avg. trail length (m)	192	283	233	138
Avg. trail width (m)	4.8	5.3	5.5	6.6
Avg. distance between trails (m)	18	38	17	37
Volume of soil removed from the trails (m^3/ha)	128	129	132	160
Surface of exposed soil under the rooting zone (m^2/ha)	345	313	455	551
Surface of exposed soil under the B horizon (m^2/ha)	0	87	50	201

iv) landings and roadside slash

Prepared landings are used during tree-length harvesting while roadside slash is created during full-tree harvesting. These two major disturbances may lead to unproductive forest areas. The landings associated with the tree-length operations create a compacted area with low organic matter content while the roadside slash of the full-tree operations is simply too dense for natural regeneration and inaccessible for artificial regeneration unless site preparation treatments are used.

For the sites surveyed, landings in the tree-length system occupied less area than roadside piles under the full-tree system (Table 9). During the timber utilization surveys, it was estimated that about half of the roadside slash was located over the landings used during full-tree harvesting. The high roadside slash coverage at Island Pond was caused by a complete use of the road network along two sides of the block.

Table 9. Area covered by landings and roadside slash.

Location	Logging method	Landings (%)	Roadside slash (%)	Surveyed area (ha)
Island Pond	TL	3.8	-	40.0
	FT	-	10.1	22.5
Rideouts Pond	FT	-	5.8	16.4
Trussle Block	FT	-	4.2	85.0
Lady Slipper	FT	-	4.4	22.7
Camp 10	TL	2.4	-	25.5

Discussion

Timber utilization

The standard timber utilization procedures used refer only to the areas actually cut. A second phase in the timber utilization survey is done after all logging has ceased. This later phase concentrates on standing residual timber. Considering the challenging terrain, the weather of western Newfoundland, and because of various machine capabilities, it is conceivable that the two logging systems could result in more solid merchantable timber being left in the operating areas than reported herein.

During the case study, the survey of timber utilization showed only minor differences between the two harvesting systems. The tree-length system left more volume on the cutover but none at roadside. When the two systems were used on the same site, the tree-length system left slightly less merchantable volume on site overall, but the full-tree system left lower stumps. Therefore, the net volume loss was in favor of full-tree.

In Nova Scotia, Gingras (1992c) observed a slightly better fibre utilization from manual felling and delimbing during tree-length operations compared to a fully-mechanized full-tree system. The fibre recovery indexes were 99% for manual tree-length and 97% for full-tree. However, this study did not consider volume gain from lower stumps.

In some cases, the higher productivity of mechanized full-tree harvesting compared with manual tree-length may be at the expense of slightly lower fibre utilization. Feller-bunchers can waste fibre by using improper felling and bunching techniques. Both skidders and stroke delimbers can lose fibre by breaking stems or by losing the smaller ones on the cutover or around the pile. However, lower stumps are often observed when using a feller-buncher for winter harvesting compared to manual harvesting.

Advance regeneration

In general, the results of this study show no evidence that full-tree logging will affect the regeneration stocking more than tree-length. The stocking after harvest was more abundant for the full-tree system in the only block where both systems were assessed side-by-side. Previous studies made in eastern Canada have not shown much difference between the two systems either (Frisque et al 1978; Ruel 1992). However, the tree-length system with manual felling may offer more potential for protecting advance growth when careful logging techniques are used (Rhéaume 1992). By using the full extension of the cable on a skidder, designated skid trails can be widely spaced during tree-length harvesting. The distance between designated skid trails during harvesting with a mechanical felling method is restricted by the reach of the boom on the feller-buncher.

The slash scattered on the site after tree-length harvesting can offer a certain shelter to natural regeneration. However, dense mats of slash may also suppress small seedlings. FERIC is currently conducting studies to evaluate the influence of the slash left on the cutover during tree-length or cut-to-length operations on natural regeneration.

Generally, in the past, insufficient natural regeneration after harvesting has not been a problem for the coastal fir sites of western Newfoundland (Richardson 1975). Stocking levels greater than 90% are not uncommon in manual tree-length cutovers. In fact, the young stands are generally too dense and have to be thinned. However, because the newly-germinated seedlings are often hard to detect right after harvest, the regeneration surveys are generally done 3 to 5 years after the cut. Since the regeneration assessments of this case study were done just after harvesting, the stocking and density results may change over the next couple of years. A second regeneration survey at year 5 would be more reliable and could lead to stronger conclusions.

Further surveys of the case study blocks are needed to verify if the regeneration after both harvesting systems follows the same evolution pattern. However, even if the type of sites and the systems were not exactly the same, the results of the 13-year-old full-tree and tree-length cut in the Burlington block seem to confirm that the evolution pattern of the natural regeneration after both systems is similar.

Should the natural regeneration evolution pattern of the case study blocks not correspond to the favorable results observed in the Burlington block, efforts could be put toward careful logging to protect advance growth. Trials conducted in Quebec show that careful logging can save an additional 10% stocking when using mechanized felling methods (Ruel, 1992). Special techniques purposely developed for the protection of advance growth are described by Canuel (1989). These techniques are based on reducing the vehicle traffic on the site and the sweeping effect when manipulating the bunches. The experience in Quebec where these techniques are commonly applied shows that no added operational costs are incurred. However, an appropriate training program is necessary to ensure successful implementation of these techniques.

Soil disturbance on the cutover

Soil disturbance should not be confused with soil degradation. Soil integrity is not affected much by light disturbance. In fact, light to medium disturbance can often be beneficial. For example, shallow mineral soil exposure can produce a good seedbed. However, a single pass of a skidder with its load can be enough to damage advance regeneration or pull seedlings out of the ground while having a low impact on soil integrity.

Isolated severe soil disturbances do not result in a loss of productive area when adjacent trees are able to use that growing space. In the case study, moderate and severe disturbances were associated with skid trails. The compaction and the absence of humus in some trails may lead to a lower soil productivity in these microsites. The disturbances could also result in further local soil degradation caused by increased erosion potential of located skid trails. On steep terrain as in the Lady Slipper and Camp 10 sites, soil disturbances may be reduced with proper skidding techniques or by putting in structures to divert running water into undisturbed areas. By reducing the quantity of initial soil displacement, erosion risk will be lessened and natural or artificial recovery processes should be more efficient.

Except for bulldozed skid trails in the tree-length sites, both harvesting systems showed comparable site disturbance results. Considering the terrain conditions encountered in the case studies, bulldozed trails created unnecessarily severe ground disturbance (Figure 4).

During the case study, sub-optimal road positioning was noticed, resulting in certain cases, in excessive uphill skidding. A greater effort is needed to drag wood up to a road, often resulting in greater soil disturbance.

a)

b)

Figure 4. Typical skid trails on steeper slopes
a) skid trail in a full-tree cutover (Lady Slipper)
b) skid trail in a tree-length cutover (Camp 10)

Area taken out of production

The amount of area taken out of forest production by logging operations can vary depending on the interpretation of the severity of the disturbances. For example, if no ingress of fir is expected after harvesting and if artificial regeneration is not planned, a 15% loss of the advance growth stocking caused by light to severe skidder disturbances could be considered as a loss of 15% of the productive area. However, an in-fill planting operation could often put most of that area back into forest production. Therefore, the area taken out of forest production will depend on management goals and practices. For the scope of this study, areas taken out of forest production were considered to be only the severe and widespread disturbances which negate almost any chance for a planted seedling to become a crop tree without an adequate site rehabilitation treatment. Under this definition, roadside slash, landings and skid trails are areas potentially out of production. The road network was not taken into account, as it was considered equivalent for both systems.

During full-tree operations, stroke delimbing at roadside produces an area of dense slash. In this case study, the 4.2 to 10.1% coverage of the roadside slash is comparable with the 2.5 to 10% coverage (average of 4.6%) measured in Quebec by the Ministère des Forêts (Canuel 1984; Canuel and Rhéaume 1987). As noted in other studies (Desrochers and Ryans 1991), slash piles occupy the whole side of the road, and can be 7 to 25 m wide and as deep as 3 m. Such a concentration of slash suppresses any potential natural regeneration. However, being long and narrow, the roadside slash piles have a high perimeter to surface ratio and offer more edges than landings for potential tree establishment.

The most common method used to rehabilitate these areas is by piling and burning the slash. If a market is available for energy, the slash can also be chipped or hogged. Even if part of the slash is in the road network, the rehabilitation treatment would be done over the whole area covered by roadside slash (an average of 4 to 5% of the area).

The wood skidded to roadside can be concentrated in smaller landings during tree-length operations. In the two tree-length blocks of the case study, the landings represented 2.4 and 3.8% of the area. These results are similar to the 1.2 to 4.1 % coverage observed by Cheeks (1983).

The tree-length landings are free of slash but heavily disturbed and compacted. Because the organic matter and the top layers of soil have been bulldozed away, they offer a poor growing medium for planted seedlings. During a visit of older landings planted by Corner Brook Pulp and Paper, it was observed that the seedlings planted about ten years ago had a fair survival rate but a slow growth rate. Even pioneer species seemed to have trouble to establish themselves. The planted trees were showing a growth gradient from the road to the cutover with improved growth the further from the road. Since the trees planted in the landing but close to the cutover will probably catch up to the rest of the forest, the whole landings cannot be considered as totally out of forest production. A full rehabilitation treatment of the landings would probably involve tillage to loosen the soil. Andrus and Froehlich (1983) report increased survival of 11 to 83% and increased height of 13 to 73% of seedlings planted after a tillage treatment of compacted forest soils. They recommend the use of winged subsoilers for all conditions except for clayey soils where disk harrows give better results. However, even the best tillage is unlikely to return a compacted soil to its original condition and productivity. To compensate for the exportation of nutrient rich upper soil horizons, a fertilization treatment would also be beneficial.

The skid trails are long and narrow disturbed and/or compacted areas distributed over the cutover. Even if the nature of disturbance can be similar to that observed on landings, the impact of trails of varying widths is different. Assuming a target spacing for seedlings of 2.25 m and no regeneration left in a 6-metre wide skid trail but the presence of a seedling on each side, the loss of potential growing area would be 3.75 m wide in the centre of the trail. By planting a row of seedlings in the centre of the trail, the loss of potential growing space would only be 1.5 m. This could be offset by keeping a closer spacing between crop trees along the edge of the skid trails during the precommercial thinning treatment. Moreover, visits to older cutovers have shown that seedlings planted in skid trails seem to have good growth potential. Therefore, if deemed necessary, skid trails could be rehabilitated with an in-fill planting treatment. However, the centre berm of the trail might be subject to erosional instability. The berm of unbulldozed trails would likely have a greater recovery potential than the berm of bulldozed trails. The berms on sites with a gentle slope should also have a better recovery potential than sites with steeper slopes.

On the basis of area taken out of forest production without a rehabilitation treatment, there would be around twice the loss of area by the full-tree roadside piles then by the landings of the tree-length the logging system. Palliative treatments are available in both cases to put landings and roadside slash piles back into forest production. However, the treatment of roadside piles is now a common practice while landing treatments have not been done at an operational scale in eastern Canada.

Nutrient removals

Most of the nutrient rich tissues are found in the tree foliage and smaller twigs. Therefore, the site fertility can potentially be impoverished by moving the delimbing residues from the stump to the roadside. Full-tree logging has raised some concerns and there is a large body of literature published on the nutrient impact with this harvesting method (Kimmins et al. 1985; Dyck et al. 1986; Foster and Morrison 1989). A review of literature on the nutrient exports with different harvesting methods was covered in a recent FERIC contract report to Forestry Canada (Richardson and Henderson 1993).

Foster and Morrison (1987) estimated the nutrient removals associated with harvesting on 100-year rotations in an upland boreal black spruce stand. They noticed an increase of 400% in N removal and 60% in Ca removal for full-tree compared with tree-length. Smith and al. (1986) estimated the nutrient removals for a full-tree harvest of a red spruce and balsam fir stand in Maine to be two to four times the amount with tree-length harvesting. Among four conifer and four hardwood stands in central Nova Scotia, Freedman and al. (1986) measured an increased uptake of 50% for biomass, 170% for N, 200% for P, 160% for K, 100% for Ca and 120% for Mg comparing full-tree harvesting to tree-length. In the short-term, with respect to impoverishment of site nutrient capital, they only express concerns about a possible shortage of calcium.

Authors generally indicate concern about full-tree harvesting for short-rotation plantations (such as hybrid poplars) or on poor quality sites with thin, coarse-textured soils. Medium to long-term rotations result in less frequent removal of nutrients, which appears to be of less ecological significance (Freedman 1981). The loss of nutrients, especially Ca, K and N, through full-tree logging may require further attention, as for dry sites with low reserves of organic matter or wet sites with excessive accumulation of organic matter (Weetman and Webber 1972). Because of a severe loss of potential N supply and a Ca balance problem, Weetman and Algar (1983) suggest to avoid full-tree logging on dry jack pine sites. Initially fertile, higher-quality sites that comprise a major part of the productive Canadian forest land base are probably at less risk to nutrient impoverishment caused by full-tree harvesting (Freedman 1991).

In Newfoundland, numerous black spruce stand types on coarse textured or shallow soils have a low fertility index and the impact of higher nutrient removals should be looked at carefully. Risk of nutrient impoverishment caused by full-tree harvesting in balsam fir stands of western Newfoundland is more likely in low fertility forest types such as Pleurozium-Balsam fir and Gaultheria-Balsam fir. In our case study, Hinds Lake was the only site with a forest type that sometimes has a low fertility index (Hylocomium-Balsam fir). However, the site had a good water seepage level which provided a higher natural fertility. Further studies are necessary to evaluate the impact of nutrient removal on these sites.

Cost analysis

i) Harvesting costs

The direct harvesting cost was defined as the sum of all the harvesting activities needed to deliver wood to roadside and expressed in $\$/m^3$. Some working assumptions were established to define the context of the analysis:

- the analysis was based on a harvest of 100 000 m^3 of pulpwood with average volumes per stem of 0.08, 0.10, 0.12 and 0.14 m^3;
- the operating cost for the machines in the two systems were calculated with the standard CPPA method (Rickards and Savage 1983) adopted by FERIC;
- the productivity figures, utilization rate of machinery, operating scheduled hours per year, expected machinery life, repair and maintenance cost, wages, fuel price and cost of oil and lubricants were supplied by Corner Brook Pulp and Paper;
- to simplify the analysis, no differences were made between winter and summer operations. (However, the productivity of feller-buncher and skidder operations may often be somewhat lower in the winter while the delimber production is usually improved when the limbs are frozen.)

Harvesting costs are summarized in Table 10. Further details of the cost analysis can be found in Appendix 2. The full-tree system was calculated to be more economical than the tree-length system. For example, the average difference is estimated at $4.33/m^3 for an average tree size of 0.10 m^3. The 15% saving occurs mainly during the felling and skidding phases. However, in the case study, bulldozed skid trails were only used in tree-length operations. If bulldozing costs were removed from the full-tree scenario, the cost difference between the two systems would be even greater.

Because of the high productivity of the full-tree system, the harvesting of 100 000 m^3 in one year requires about 9 machines with only 17 operators (Table 11). The tree-length system needs about 20 machines and 54 operators to harvest the same annual volume. The total wages paid were estimated at 2.43 times higher to harvest 100 000 m^3 annually. Despite a lower number of machines required in the full-tree system, the capital investment is slightly higher than in the tree-length system.

Table 10. Direct harvesting costs by tree size of harvesting activities for full-tree and tree-length systems

Harvesting activity	Cost ($/m^3)							
	Full-tree				Tree-length			
	0.08	0.10	0.12	0.14	0.08	0.10	0.12	0.14
Felling	9.70	8.14	7.20	6.60	13.53	11.90	10.73	9.82
Skidding	8.83	7.74	6.96	6.36	13.27	11.67	10.52	9.63
Delimbing	4.42	3.86	3.46	3.15	-	-	-	-
Slashing*	2.92	2.73	2.56	2.44	3.53	3.29	3.10	2.94
Bulldozing	2.39	2.39	2.39	2.39	2.33	2.33	2.33	2.33
TOTAL	28.26	24.86	22.57	20.94	32.66	29.19	26.69	24.72

*Lower slashing costs for the full-tree system result from more efficient piling.

Table 11. Machine and labour costs by tree size for full-tree and tree-length systems.

	Full-tree				Tree-length			
	0.08	0.10	0.12	0.14	0.08	0.10	0.12	0.14
Workers (nb)	19.97	17.65	16.06	14.90	63.21	55.93	50.66	46.58
Capital investment ($M)	2.84	2.54	2.34	2.20	2.46	2.24	2.08	1.96
Machine owning ($\$/m^3$)	8.68	7.68	7.00	6.53	5.60	5.09	4.73	4.44
Machine operation ($\$/m^3$)	10.37	9.07	8.21	7.60	4.74	4.31	4.00	3.75
Labour and fringe ($\$/m^3$)	9.21	8.11	7.36	6.81	22.32	19.79	17.96	16.53
TOTAL ($\$/m^3$)	28.26	24.86	22.57	20.94	32.66	29.19	26.69	24.72

ii) Renewal options

Two renewal options were analyzed for full-tree and tree-length harvesting. Depending on the success of advance growth protection, the options will lead to natural or artificial regeneration. The net present value of each renewal option treatment was calculated using the year of harvest as year 0 and a 5% discount rate. The following assumptions were used in the cost analysis:

Option 1 (natural regeneration)

- the stocking of natural regeneration after harvesting is sufficient;
- the stand density is typically high (>50000 stems/ha) and a precommercial thinning treatment will be needed at age 12. The estimated cost of this treatment is $1000/ha;
- following conventional regeneration practices in Canada, no specific treatments are used to rehabilitate the landing area after tree-length operations.

Roadside slash

- roadside slash covers 5% of the cutover area;
- rehabilitation is done by raking and burning the slash piles;
- piles are raked to fluff up the debris to facilitate drying for subsequent burning. The estimated raking cost is $330/ha treated;
- burning is done at a cost of $75/ha treated;
- planting is done at a rate of $750/ha ($300/ha for seedling production and $450/ha for planting operations).

Option 2 (artificial regeneration)

- natural regeneration is insufficient (sparse fir cover);
- planting the whole cutover is done at a cost of $750/ha;
- roadside slash are put back into production using the same techniques as for Option 1;
- site preparation treatment might be required on some sites. Powered disc trenching would cost around $185/ha;

- since the fir cover is sparse, competition by unwanted vegetation may create some problems. A herbicide treatment at age 5 is estimated to be $200/ha;
- the natural regeneration might also have to be cleaned out of the plantation. The cleaning cost for a density of less than 20 000 stems/ha is evaluated at $400/ha.

The direct treatment costs of the two renewal options are detailed in Table 12. Assuming sufficient natural regeneration, the renewal costs is estimated to be $4.55/m^3$ for the full-tree system and $4.15/m^3$ for the tree-length system. The cost of artificial regeneration is similar for both harvesting systems. A minimum rate for this option is the planting cost of $5.04/m^3$ onto which site rehabilitation, site preparation, herbicide and cleaning costs could be added depending on site and stand conditions.

For the natural regeneration option, the total direct harvesting/renewal costs for the full-tree system is $3.93/m^3$ lower than for the tree-length system (Table 13). Even if artificial regeneration was needed with the full-tree system and not with the tree-length, the cost difference could still be in favor of full-tree. The maximum cost of the artificial regeneration option with the full-tree system is only $0.86/m^3$ higher than the natural regeneration option with the tree-length system. If no site preparation was needed, as is usually the case in western Newfoundland, the renewal costs would be $0.47/m^3$ cheaper for the full-tree system. Furthermore, the artificial regeneration might provide a lower susceptibility to insect infestation and an added value to the stand by increasing the spruce content via planting. However, a risk analysis and the economic impact of a higher final product value is beyond the scope of this study.

The treatment of landings is not done anywhere in Canada on an operational scale. However, a rehabilitation treatment could be tried by subsoiling and fertilizing the area. According to costs provided by Weyerhaeuser and reported by De Long and Al. (1990), a subsoiling treatment would cost $300/ha treated. To avoid rapid leaching of the fertilizer, the use of transplant fertilizer pouches applied during planting may be more feasible. The cost of the pouches is $0.11/seedling and the assumed added planting cost for their application is $0.02/seedling for a total cost of $260/ha planted. Assuming that the landings occupy 3% of the cutover area, the cost for their rehabilitation would be $0.26/m^3$ ($0.06/m^3$ for subsoiling, $0.05/m^3$ for fertilization and $0.15/m^3$ for planting).

Table 12. Renewal costs for natural regeneration (Option 1) or artificial regeneration (Option 2).

Renewal option treatments	Cost ($/ha)	Years after harvest	Net present value ($/ha)	Cost ($/m³)*	Total ($/m³)	
Option 1						
Precommercial thinning	1000	12	560	4.15	4.15	
Roadside slash						
Raking	330	1	310	0.12		
Burning	75	1	70	0.03		
Planting	750	2	680	0.25	0.40	
Option 2						
Roadside slash**	-	1	-	0.15		
Planting	750	2	680	5.04		
Site preparation**	185	1	180	1.33		
Herbicide**	200	5	160	1.19		
Cleaning**	400	12	220	1.63	9.34	max.

* To convert $/ha to $/m³, the assumed stand volume is 135 m³/ha ; 2700 m³/ha of roadside slash - 5%.

** These treatments might not be required.

Table 13. Total direct harvesting and renewal costs for full-tree and tree-length harvesting systems (average tree size of 0.10 m³/tree).

Harvesting system	Harvesting cost ($/m³)	Silviculture cost ($/m³)			Total cost ($/m³)		
		Option 1	Option 2		Option 1	Option 2	
			min.	max.		min.	max.
Full-tree	24.86	4.55	5.19	9.34	29.41	30.05	34.20
Tree-length	29.19	4.15*	5.04**	9.19**	33.34	34.23	38.38

* treatment of landings would add $0.26/m³ for subsoiling, fertilization and planting.

** treatment of landings would add $0.11/m³ for subsoiling and fertilization.

Conclusions and Recommendations

Overall, *on the sites where they were studied*, no major differences were found between full-tree and tree-length harvesting in terms of timber utilization and protection of advance regeneration. The differences in soil disturbances were not directly related to a particular harvesting system but mostly to the use of bulldozed skid trails with the tree-length system. With the assumptions used, full-tree logging had a 15% lower direct harvesting cost than manual tree-length.

The roadside delimber slash of full-tree logging covered around twice the area compared to the prepared landings created during tree-length logging. Without a rehabilitation treatment, the roadside slash will take more area out of production than the tree-length landings. When adding the site rehabilitation costs to the harvesting cost, the full-tree system remains cheaper. In some situations, the overall cost of harvesting and forest renewal using artificial regeneration following a full-tree harvest could still be lower than the cost of tree-length using natural regeneration.

For the treatment of roadside slash piles, the method most easily applied would consist of a piling and burning system. Although burning the piles in-situ can be effective in some areas, the maritime climate and low-lying valley bottoms typical of western Newfoundland hampers the drying of in-situ piles. Thus, some form of piling operation will be required prior to burning to overturn and introduce air pockets to facilitate drying. The piling operation also creates a buffer area between the edge of any standing timber and the piles to be burned.

A bulldozer equipped with a piling rake would be the most versatile tool for the piling operation, considering the slope conditions and the general lack of large skidders in the province. An excavator with a homemade rake attachment could also be used.

A potential drawback of full-tree harvesting is the risk of nutrient removal caused by exporting delimbing residues to roadside. This system should be avoided on the poorer sites until further studies evaluate the impact of higher nutrient losses on these sites. Also, this highly mechanized system employs a smaller work force which can be perceived as an advantage or a disadvantage depending on one's perspective.

Proposed improvements to the harvesting systems

- Bulldozing skid trails should be avoided except on very steep slopes where they provide a better access to cable skidders. Where bulldozing is necessary, careful road planning and trail layout will be critical to reduce levels of initial soil displacement and the potential for subsequent erosion. The use of tire chains or wide tires could improve skidder access on intermediate slopes.
- Designated skid trails and other careful logging techniques should be adopted. They could improve public perception of logging

operations through improved aesthetics and provide better protection of the advance growth. When well planned, these trails can also minimize erosion problems.

- Manual tree-length harvesting is a more flexible operation and should be preferred for very steep terrain where feller-buncher access is limited.
- A recuperator grapple can be mounted on the skidder blade to pick up forgotten or lost stems. This would improve productivity as well as fibre recovery.
- Plan road positioning to reduce uphill skidding. This would improve productivity, reduce operating costs and lower soil disturbance levels.
- To eliminate roadside slash of full-tree systems yet retain the cost advantages of mechanization, other alternatives such as cut-to-length systems and mechanized tree-length could be considered. The feller-buncher/processor/forwarder system is productive, yet is gentle on the soil and leaves slash on the cutover. FERIC is also currently studying the viability of various mechanized tree-length systems.

This case study was extensive but covered only a short time period. Follow-up studies should be conducted to monitor the evolution of the stands resulting from the two harvesting systems. The effects of using designated skid trails and careful logging techniques, as well as the productivity and cost impacts of minimizing the use of bulldozed skid trails should also be studied.

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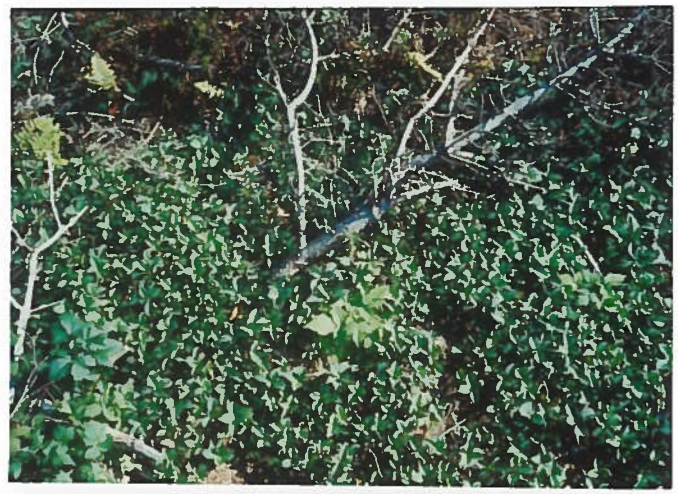
APPENDIX 1

DEFINITION OF SITE DISTURBANCES

Undisturbed soil or vegetation slightly scuffed

The soil does not show physical alterations due to harvesting operations. Lower vegetation may have been swept but the humus layer is intact.



Humus disturbed

Disturbance of the humus layer exclusively. It includes torn up humus or exposed fibric or humic sub-layers of the humus layer.

Mineral soil deposit

Mineral soil displaced covering slash or undisturbed soil.

Shallow mineral soil exposure

Exposure of mineral soil within the zone encompassing 90% of the roots (approximately 10 cm).

Mix of mineral soil and organic matter

Intimate mix of mineral soil with litter, vegetation and other organic matter.

Deep mineral soil exposure

Mineral soil exposure below the rooting zone (generally deeper than 10 cm).

Muck

Mineral or organic muck caused by the passage of a machine over wet soils.

Erosion features

Occurrences of erosion features such as rills, gullies and sediment zones. The soil is unstable and still subject to further runoff erosion.

No evaluation possible

No evaluation of the soil disturbance is possible because of a thick cover of slash or other debris.

No disturbance possible

Area covered by ground obstacles such as stumps and boulders.

APPENDIX 2

DIRECT HARVESTING COSTS: ASSUMPTIONS & RESULTS

	FB 630B	Grap skid JD648	Cab skid JD640	Slasher CC100	Delimber K200	Bulldozer D7H	Cab skid TJ230	Slasher CC100	Bulldozer D6
INPUTS:									
Mach life (yrs)	4	4	4	4	4	12	8	4	12
SMH/ year	4000	4000	4000	4000	4000	1440	1440	4000	1440
Purchase price ($)	400000	169600	152000	201500	264500	375000	83000	201500	259000
Salvage value ($)	40000	33920	30400	20150	26450	75000	16600	20150	51800
Licence cost ($/yr)	0	0	0	0	0	0	0	0	0
Insurance ($/yr)	20000	8480	7600	10075	13225	18750	4150	10075	12950
Interest rate (.%)	10%	10%	10%	10%	10%	10%	10%	10%	10%
Utilization (.%)	75%	85%	85%	85%	85%	90%	85%	85%	90%
Life repair costs ($)	600000	169600	152000	201500	264500	375000	83000	201500	259000
Fuel cons. (l/PMH)	25.2	20.9	20.9	19.1	14.8	20.4	8.1	19.1	18.1
Fuel price ($/l)	0.35	0.35	0.35	0.35	0.35	0.46	0.35	0.35	0.46
Oil + Lub ($/PMH)	4.41	1.10	1.10	3.34	2.59	0.94	0.43	3.34	0.83
Wages ($/SMH)	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58
FIXED COST:									
$Capital/year	117569	46195	41401	59226	77743	51529	14106	59226	35589
$Others/year	20000	8480	7600	10075	13225	18750	4150	10075	12950
$/year	137569	54675	49001	69301	90968	70279	18256	69301	48539
$/ PMH	45.86	16.08	14.41	20.38	26.76	54.23	14.92	20.38	37.45
$/SMH	34.39	13.67	12.25	17.33	22.74	48.80	12.68	17.33	33.71
VARIABLE COST:									
$/year	189690	71011	66611	84460	92543	44628	14371	84460	33450
$/ PMH	63.23	20.89	19.59	24.84	27.22	34.44	11.74	24.84	25.81
$/SMH	47.42	17.75	16.65	21.12	23.14	30.99	9.98	21.12	23.23
LABOUR COST:									
$/year	94320	94320	94320	94320	94320	33955	33955	94320	33955
$/ PMH	31.44	27.74	27.74	27.74	27.74	26.20	27.74	27.74	26.20
$/SMH	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58
TOTAL COST:									
$/year	421579	220006	209932	248081	277831	148862	66583	248081	115944
$/ PMH	140.53	64.71	61.74	72.96	81.71	114.86	54.40	72.96	89.46
$/SMH	105.39	55.00	52.48	62.02	69.46	103.38	46.24	62.02	80.52
PROD (m^3/PMH):									
at .08 m^3/tree	14.49	7.5	6.84	24.96	18.48	48	4.1	20.71	38.4
at .10 m^3/tree	17.26	8.59	7.77	26.76	21.17	48	4.66	22.23	38.4
at .12 m^3/tree	19.52	9.59	8.62	28.38	23.64	48	5.17	23.55	38.4
at .14 m^3/tree	21.28	10.53	9.41	29.8	25.96	48	5.65	24.73	38.4
COST ($/$m^3$):									
at .08 m^3/tree	9.70	8.63	9.03	2.92	4.42	2.39	13.27	3.52	2.33
at .10 m^3/tree	8.14	7.53	7.95	2.73	3.86	2.39	11.67	3.28	2.33
at .12 m^3/tree	7.20	6.75	7.16	2.57	3.46	2.39	10.52	3.10	2.33
at .14 m^3/tree	6.60	6.15	6.56	2.45	3.15	2.39	9.63	2.95	2.33